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(6) MILITARY RESEARCH ON JET FUEL CONTAMINATION

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MILITARY RESEARCH ON JET FUEL CONTAMINATION

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ABSTRACT

Serious aircraft troubles, including engine flameouts, fuel gage malfunctions, integral tank corrosion, and other fuel system difficulties have been traced to contaminants in the fuel. The chief offenders, singly or in combination, ~~have been~~ were found to be water, dirt (especially iron rust), surfactants, and microorganisms.

Improper operation and maintenance of fuel handling equipment ~~has been~~ was found to be the causative factor in each case of serious fuel contamination thus far investigated. The consensus of informed opinion is that the troubles encountered in field handling of fuels can be averted by good housekeeping throughout the fuel handling system.

BACKGROUND

It has been found that fuel contamination has been the cause of engine flameouts, fuel gage malfunctions, integral tank corrosion, and other fuel system difficulties. The contaminants responsible for these troubles have been water, dirt (especially iron rust), surfactants, and microorganisms -- either singly or in combination.

Jet engines are more sensitive to all forms of fuel contamination than are piston engines because of the finer passages in metering systems and nozzles. Jet fuels are more viscous than gasolines, and thus less easily cleaned by settling. In addition, some commercial practices can not be used in aircraft operation. Aircraft tanks must be pumped empty, as all of the fuel must be used. There is little or no chance for contaminants to settle out in aircraft tanks. Much the same is true of the immediate logistic support facilities, at least under combat conditions.

When filter/separator equipment is not properly maintained, or when surfactants are present (even to the extent of 0.5 ppm), water carrying dirt and microbes may pass through the filter/separator. These contaminants can cause corrosion and malfunctioning of fuel controls and fuel probes.

The microbes produce an environment which permits attack on the aircraft tank coating and corrosion results. Rust particles can cause corrosion by electrolytic action. In extreme cases corrosion has proceeded to an extent such as to threaten the structural integrity of the aircraft. In Australia, this form of attack has resulted in leakage of fuel through the wing skin of aircraft. It has also been found that microbes could flourish in the laboratory in rocket fuel RP-1. However, this is not considered serious, as the small volume allows special handling, the missile fuel system is sealed, and the fuel is changed periodically to avoid chemical degradation.

The problem of fuel contamination has long been a matter of concern. In 1955, some aircraft carriers experienced trouble from dirt and water contamination so severe as to render their aircraft inoperative. At the request of the Navy, an ad hoc study group was formed of consultants and staff of the then Technical Advisory Panel on Fuels and Lubricants. Their study led to publication of "Recommended Corrective Measures for Handling Aviation Turbine Fuels," (1), a report which received wide distribution. Improvements in fuel system design, and meticulous care of the handling equipment overcame most of this trouble. Soon thereafter microbial contamination was encountered, but was later eliminated. Since 1959 no serious trouble of either sort has been experienced by the Navy.

Early in 1961 the problem of fuel contamination again arose in Air Force as it had in commercial airline operations, both here and in the Far East. Especially serious trouble arose at Ramey Air Force Base in Puerto Rico. Extensive corrosion of the integral tanks developed, apparently as a result of microbial attack on the tank lining. At the request of the Air Force a team of our consultants was organized and sent to Ramey. Their study disclosed that unusual amounts of surfactants in the fuel were a major contributor to the trouble. This factor had not been recognized previously as being important. Since this phase of the problem was not generally appreciated, a symposium on fuel contamination was organized by the Fuels and Lubricants Division and was held in September 1961 (23), to inform industry and the military of the findings and recommendations of our consultant team. A DoD news release (29) on jet fuel contaminants was issued early in 1962.

Through the first and subsequent visit to Ramey, it became clearly apparent that microbial attack is but one facet of the overall problem of fuel contamination. Although surfactant-free fuel was immediately furnished to Ramey, and filter/separator maintenance was improved, it was many months before the base tanks could be cleaned. Despite this, inspections before tank cleaning showed that even though microorganisms were still present in the tanks, the fuel delivered to aircraft was clean and dry. However, some further corrosion of aircraft tanks was reported.

Means for removing particulate matter and water have been well worked out and require only conscientious application to yield clean, dry fuel. Work is in progress to develop the still more efficient filter/separators which will be required to process fuel for higher-speed aircraft, and to develop much lighter units for special applications. The fact that surfactants which may be present in the fuel greatly degrade the effectiveness of filter/separators has been recognized only recently. While development of sensitive means for their detection is fairly well along, needed research on evaluation of their effects on filter/separators is not fully underway. Thus at present more research is being directed at microbial growths than to the other equally important factors in fuel contamination. As this is a report of military research on fuel contamination, the larger space devoted to microbe studies should not be construed as an indication that they are more important than the other factors.

MILITARY PROGRAMS

Filter/Water Separators

In accordance with a recommendation of our Petroleum Handling Equipment Group, responsibility for all acceptance tests of filter/separators was assigned to the US Army Engineer Research and Development Laboratories (ERDL) by the Assistant Secretary of Defense for Installations and Logistics. Previously, units accepted elsewhere were sometimes found by ERDL to fail to meet the specifications. It is believed that the assignment of single Service responsibility will result in a more uniform product. ERDL has designed a military standard filter/separator element, which is being used in or phased into equipment of the three Services.

ERDL is presently revising the designs of the family of filter/separators, to reduce the weight. Through a minor change, the allowable flow rate per element has been doubled. By eliminating automatic controls, and by using lightweight alloys, a 300 gpm unit which weighed 1400 pounds has been replaced with one weighing 500 pounds. Comparable reductions have been made in larger and smaller units. Quartermaster Research and Engineering Command work is directed toward extremely lightweight, compact equipment for air transport.

Devices for Detecting Water and Particulate Matter in Fuel

At the request of the military departments, our Petroleum Handling Equipment Group set up a task unit to review and coordinate research being conducted by each of the Services on fuel contamination detectors. It was the consensus that multiple approaches were warranted in this relatively new area, but that the work of each Service should be discussed frequently with the other Services. This coordination is being sponsored by the Fuels and Lubricants Division.

Three devices merit and are receiving extensive study. These are the Bendix GO/NO-GO gage, a collecting fuse; the United Research capacitance-type monitor; and the Bowser Totamitor, a light-scattering device that looks at all the fuel in a 4" or 6" pipe. Some interest has also been shown in the Aquascan, developed by the British Petroleum Company. The Bendix system is getting the most attention, as all three military departments are experimenting with it. The Navy has decided to put this equipment on all fuel-handling equipment in their shore-based installations. The Navy has purchased three of the United Research early prototype monitors, and the Army will procure two or three Bowser units for comparison with the United Research item.

The Navy has reported good results on the GO/NO-GO gage. In trials, this device has shut down flow very quickly when water got into the system. The gage seems to have an adequate life and is not plugged by a small amount of dirt and rust in the fuel. The Navy finds the United Research monitor does not meet their needs, as it does not register on very fine particles. Two Totamitors are being purchased. One will be sent to the Aeronautical Engine Laboratory for study, and the other will be placed at the end of a 95-mile pipeline. It is hoped that six months field experience with the latter will yield information on the capability of this device.

The Air Force reported unsatisfactory results from tests of GO/NO-GO gages at Castle Air Force Base. This has been discussed with Bendix, who will study the results and endeavor to improve the instrument. Some laboratory work has been done on the Totamitor which has proved to be very accurate in indicating water. No work has been done as yet on measuring dirt with the Totamitor.

Surfactants

Much of the trouble being experienced with filter/separators is believed to come from surfactants which destroy the effectiveness of the filter, and prevent the settling and the coalescing of water. Water and dirt then get into aircraft and cause trouble both directly and by promoting microbial growth. For example, an air base in the South was receiving fuel which was known to be sterile. Despite this, the base had a bad history of operation. Recent examination showed that the delivered fuel contained surfactants, as was the case at Ramey AFB.

A limited number of commercial aircraft have been found to have severe corrosion troubles, with pitting as deep as 25% of the skin thickness. No evidence of abnormally high microbial counts was found, but surfactants were noted to be present.

Surfactants may get into fuel from a number of sources, such as residues from refinery processes, contamination in tank or pipeline shipment, by addition of some types of inhibitors. Thus when trouble

arises many potential sources must be examined, and a complete overhaul of the distribution system may be necessary.

The Naval Research Laboratory is making a study of the role of surfactants. Most corrosion inhibitors have some surfactant effect. Many parts of the country are receiving fuels with high concentrations of surfactants but are not experiencing trouble. Thus the other conditions which must exist to cause trouble are not present. NRL studies have shown no significant increase in surfactant concentration as a result of microbial growth in fuels.

The Air Force has redirected some of its fuel contamination studies as a result of consultant recommendations in meetings of the Aircraft Fuels and Lubricants Group of our Division, with more emphasis being placed on surfactants and particulate contaminants. Major programs cover studies of all contaminant and microbial factors, both singly and in combination, including environmental factors which cause growth, sludge formation, corrosion processes, deterioration of fuel systems and materials, and the possible effects of electric current on corrosion. A contract has been awarded for a special study of the role of surfactants.

Microbial Growths

1. Air Force Program

The presence of microbial growths in petroleum products has long been known. Bacteria and fungi are probably always present in fuel systems. These growths generally occur only at the water-fuel interface, in storage tanks, or in pipe lines. The microbes must have water and inorganic nutrients from which to get their mineral needs, and fuel to furnish their carbon. Before the advent of jet fuel, little or no trouble was experienced from these growths except when conditions favored sulfate-reducing growths. The latter caused the fuel to become corrosive.

The Air Force work being done by the Army Chemical Corps is directed at elucidating the relationship between corrosion and bacterial and fungal action. This includes study of sludge formation as related to fuel properties, the degree of microbial participation in corrosion, and the degradation of structural materials comprising parts of the aircraft fuel system. About 150 species of microorganisms have been found in fuel although refinery deliveries are almost always sterile, and in rare cases are even bactericidal or fungicidal. The role of microbes in modifying fuel properties, and the effect of fuel composition (including fuel additives) on microbial growth is under study, as is the role of environmental conditions. Studies are being made to determine which species are the more detrimental to coatings and sealants, and which cause the greater corrosion. As it is known that colonies on metal will in time set up a barrier that is impervious to

toxic agents, this phenomenon is being studied. Both static and dynamic conditions will be employed, since some of the effects are related to agitation of the media.

Research is in progress to determine the effect of fuel fractions, and of pure hydrocarbons, on microbial growths. Components which promote growth, and those which inhibit growth, are both of interest. Twenty-three whole fuels, including JP-4, JP-6, RP-1, and the thermally stable jet fuel (MIL-F-25524) have been evaluated. Two of these permitted only very slow microbial growth. These fuels, together with one of the more susceptible fuels, are being fractionated in an attempt to determine the fractions causing these behaviors. Of the pure hydrocarbons studied to date, the straight chain paraffins have supported growth best. None of the naphthenes were susceptible to attack.

Research is in progress on both the detection and the mechanism of microbial contamination of fuels. The first phase is directed at rapid detection of microbes, and if possible, estimation of their corrosive activity through a number of electrical, optical, and chemical techniques. The second phase encompasses a broad study of the roles of contaminants including microorganisms in combination with water, iron rust, other extraneous solids, and surfactants in the degradation of jet fuel, in sludge and slime formation, and in the corrosion or deterioration of aircraft fuel system materials.

Work is underway to determine the effect of microbial corrosion on the mechanical properties of materials used in fuel cell structures. Fatigue data for reference will be obtained from chemically and biologically corroded specimens. Depths and types of corrosion have been determined on specimens from military aircraft.

An investigation is being made of the possibility of detecting corrosion of integral fuel tanks without defueling the aircraft, by use of ultrasonic scanning. If feasible, this would save maintenance and aircraft down time.

Jet fuel system sealants and coatings capable of resisting microbial deterioration or growth are being sought. This may require biocide-elastomer combinations or organism-resistant elastomers. The majority of biocides examined thus far have had a detrimental effect on the elastomers, or have leached out. Preliminary results have indicated that the microbial population of standard fuel system sealants and coatings is quite low.

Mechanical techniques for killing, removing, or controlling microbes in fuels are under study. Techniques include filters, ion exchange resins, electrostatic precipitation, centrifugation, radiation from microwaves to nuclear, ultrasonics, and others. Currently,

filtration by cellulose ester membrane with a pore size of under half a micron, and radiation at 27.5 megacycles are indicated to offer promise.

A contract has been let for a review report on the available data pertaining to the causes and control of microbial contamination and corrosion of materials and equipment used in storing and handling jet fuel.

An investigation, including laboratory analyses and evaluation, is being made of air base fuel handling procedures with regard to contaminants including microbes. Three bases will be studied to evolve optimum procedures for controlling contamination.

A comprehensive field study of the behavior of fuel systems in the presence of contamination is being carried out at Kindley Air Force Base, Bermuda as an Air Force-Army project. The major objectives are to determine the effects of microbial growths on the water and dirt removal capabilities of filter/separators, whether the latter remove the growths, and whether the microorganisms clog or attack the filters or any other equipment in the fuel handling system. It has been recommended to the Air Force that this field study include the effects of surfactants. A recent inspection by our consultants, at the request of the Air Force, indicated that the facilities are ideal for the purpose. There are duplicate fuel systems for JP-4 as well as for aviation gasoline. One of the JP-4 systems is being used as a control, while the other is used with contamination added. Excellent laboratory facilities manned by competent personnel are available for analytical work. One part of the jet fuel system was treated with a mixed heavy inoculum of microorganisms. A variety of filter/separator types are being used. After nine months operation with about four million gallons throughput, observations are as follows:

A. Microorganisms are growing at an accelerating rate.

B. Microbial counts are increasing in the fuel but are several orders of magnitude less than in the water bottoms.

C. None of the filter/separators appears to remove the microbes now present in the fuel.

D. No evidence of surfactants has been found by Water Separometer or interfacial tension tests. No surfactants have been introduced into the system as yet.

E. No evidence has been noted of filter plugging, nor has passage of water or dirt been noted in any of the filter/separator units, although the microbial counts of the water bottoms exceed 10^9 per 100 ml.

A number of static drum tests are also in progress at Kindley AFB. Several different biocides both water-soluble and fuel-soluble, an anti-icing agent, and two surfactant materials are under study. The use of 2% potassium dichromate in the water phase of two drums has had little or no effect on microbial growth.

In addition to contractual effort, in-house studies are in progress in the following areas:

A. Investigation of the ecological relationships in a simulated fuel tank to clarify the importance of the sequential appearance of particular microbial entities with respect to environmental effects as well as to obtain pertinent information on the inadequacies of present sampling techniques.

B. Effective concentration of dichromate, and/or chromate, and anti-icing additive required for control of microbial growth in water phase and on metal surfaces. This will include observations on the presence of resistant forms of microorganisms after prolonged storage times.

C. Development of culture media and methods for isolation of both anaerobic and aerobic organisms.

D. Evaluation of experimental inhibitors for use as aircraft wash-rinse materials.

E. Investigation of on-site culturing versus culturing of shipped samples.

F. Evaluation of corrosometer probes to detect microbiological growth and/or corrosive activity.

G. Development of a qualitative method for detection of living microorganisms based on the measurement of carbon dioxide produced by cellular respiration.

In reporting field experience, the Air Force stated that fuel quality at Ramey AFB had improved remarkably since the recommendations of our consultant team were put into effect. Even though some salt water is coming ashore with tanker fuel shipments, the Ramey fuel is going into aircraft clean and dry. In February 1963 our consultant team inspected four aircraft. In each the degree of contamination was noted to be extremely light, with no significant corrosion. The condition of the top coatings was very good.

A major case of fuel contamination occurred recently at a midwest air base where water from leaky roof drains, accumulating as ice in fuel storage tanks during the winter, suddenly thawed and

overloaded the filter/separator system. This points up the absolute necessity of maintaining all equipment connected with fuel storage, handling, and dispensing in top shape. Water Separometer tests indicated the base fuel to be poor but improving as it was diluted by clean dry fuel delivered by the three suppliers. Although bacteria were found in the aircraft, the Wright-Field inspection team believed the trouble stemmed chiefly from suddenly overloading the filtration system with water, dirt, and rust. Once the water was gotten out of the tanks the problem rapidly diminished.

2. Army Program

The Army has as yet reported little or no trouble with fuel contamination, and hence looks to the other Services for answers to aviation fuel problems. With the advent of Compression Ignition engine fuel in the near future, the Army may begin having trouble. Army Research Office has made some study of the interrelation of microbial growths and fuels. The Fungicides and Germicides Branch of the Quartermaster Research and Engineering Command is completing a study of the magnitude and significance of the fuel contamination problem in the Army. They are also conducting a rather extensive study of the role of microorganisms in the degradation of fuels. In this work it has been found necessary to grow and characterize the microbes at the point where they are found, as the character of the population may change in transit. Considerable effort is being concentrated on microbe ecology. Studies are in progress to learn how the microbes live, what they eat, how they form sludge and slime, whether there is symbosis, etc. Both aerobic and anaerobic bacteria are being cultured, as well as fungi, yeasts, and actinomycetes.

Studies are in progress on the mechanism of microbial breakdown of fuels, and of fuel handling, transportation, and storage equipment. Possible microbial alterations of the hydrocarbon molecule, and the biochemistry of sludges, slimes, and emulsions are under investigation. The roles of dissolved oxygen, free water, and dirt as nutrients will be studied, as well as the biochemical mechanisms and energy transfer involved in the biological acceleration of metal corrosion. Studies are proceeding on biocides and means for preventing microbial attack on fuels and fuel systems.

3. Navy Programs

Some time ago aviation gasoline on the carrier Antietam began going sour after only a short time, although JP-4 in an identical fuel system remained sweet. The same situation occurred at the Bermuda Naval Base. Recently, however, another carrier has had a case of jet fuel going sour from microbial action. The Naval Research Laboratory has accordingly made a study of these bacteria. The problem has apparently been reduced by cleaning the tanks and by treatment of the water bottoms with sodium chromate.

NRL is monitoring fleet fuel samples, and studying biocides and resistant coatings for fuel containers. A fundamental program is being carried on to ascertain the hydrocarbon preferences of the various microbes. This work utilizes pure hydrocarbons; it has been found that some organisms can thrive on any straight chain from 8 to 36 carbon atoms. Work is also under way to learn the effects of microbes on fuel quality and the surfactant nature of the fuel. Studies to date suggest that the microbes may consume surfactants rather than producing them. Work is under way on the effects of microbes on fuel tank coatings and sealing compounds.

CONCLUSION

Improper operation and maintenance of fuel handling equipment has been found to be the causative factor in each case of serious fuel contamination thus far investigated.

The consensus of informed opinion is that the troubles encountered in field handling of fuels can be averted by good housekeeping throughout the fuel handling system.

ACKNOWLEDGMENT

The results discussed herein have been obtained by the military departments through in-house or contract research. Major contributions in facility inspections and in evaluation of the findings have been made by groups advisory to the Fuels and Lubricants Division. The constructive comments by a number of Service personnel on earlier drafts of this report have been most helpful and are gratefully acknowledged.

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